ME 321: Fluid Mechanics-I

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Lecture - 01 (12/04/2025)
Fluid Dynamics: Introduction

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Fluid dynamics

Fluid dynamics is the science dealing with the motion of fluids.
Fluids, unlike solids, **cannot** assume a fixed shape under load and **will immediately deform** (liquid and gas).

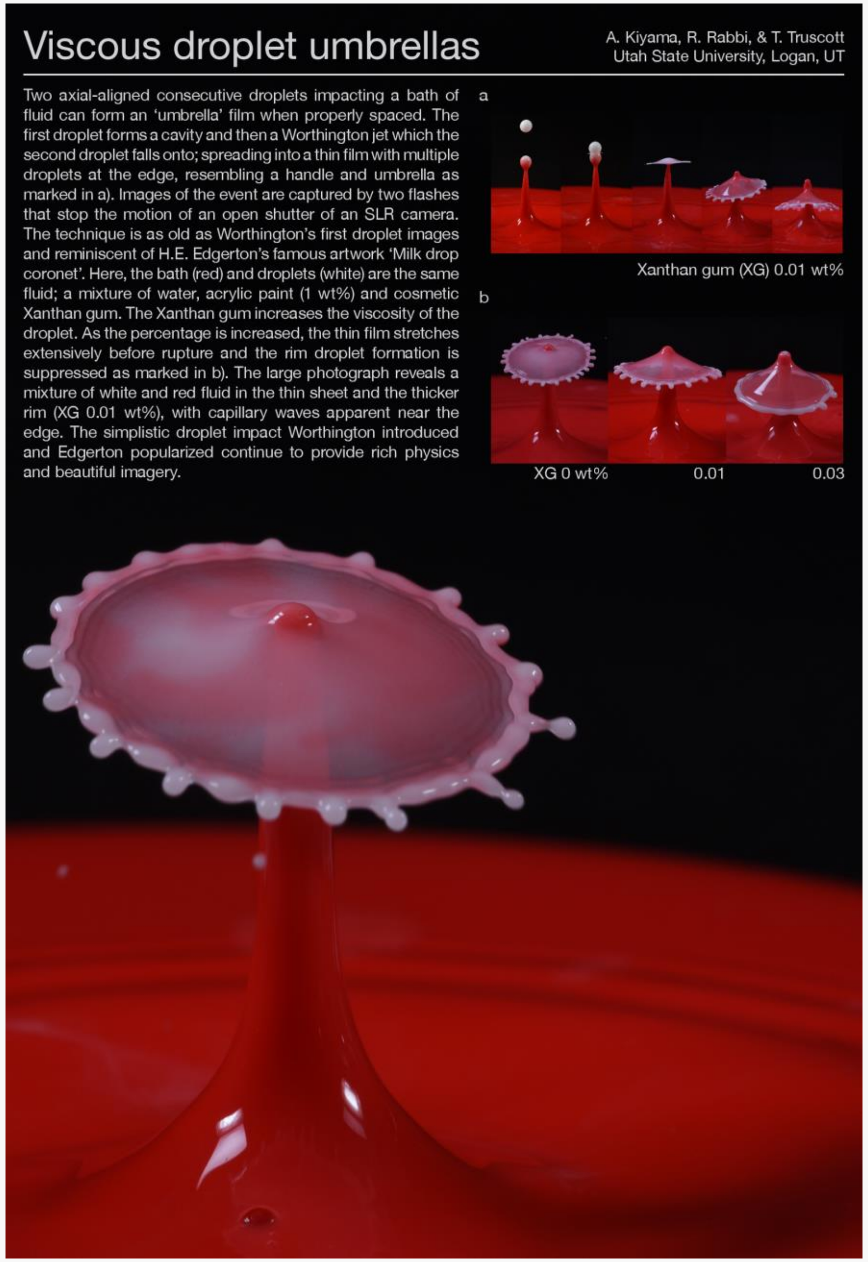
Fluid dynamics can be studied by *focusing on a particle* (Lagrangian approach) or *focusing at a point in fluid (Eulerian approach)* to understand the nature of flow. It covers a vast array of phenomena that occur in nature, modern engineering inventions, biology, life sciences, and so on.

Hurricane
(2023: Midhili, Hamoon)

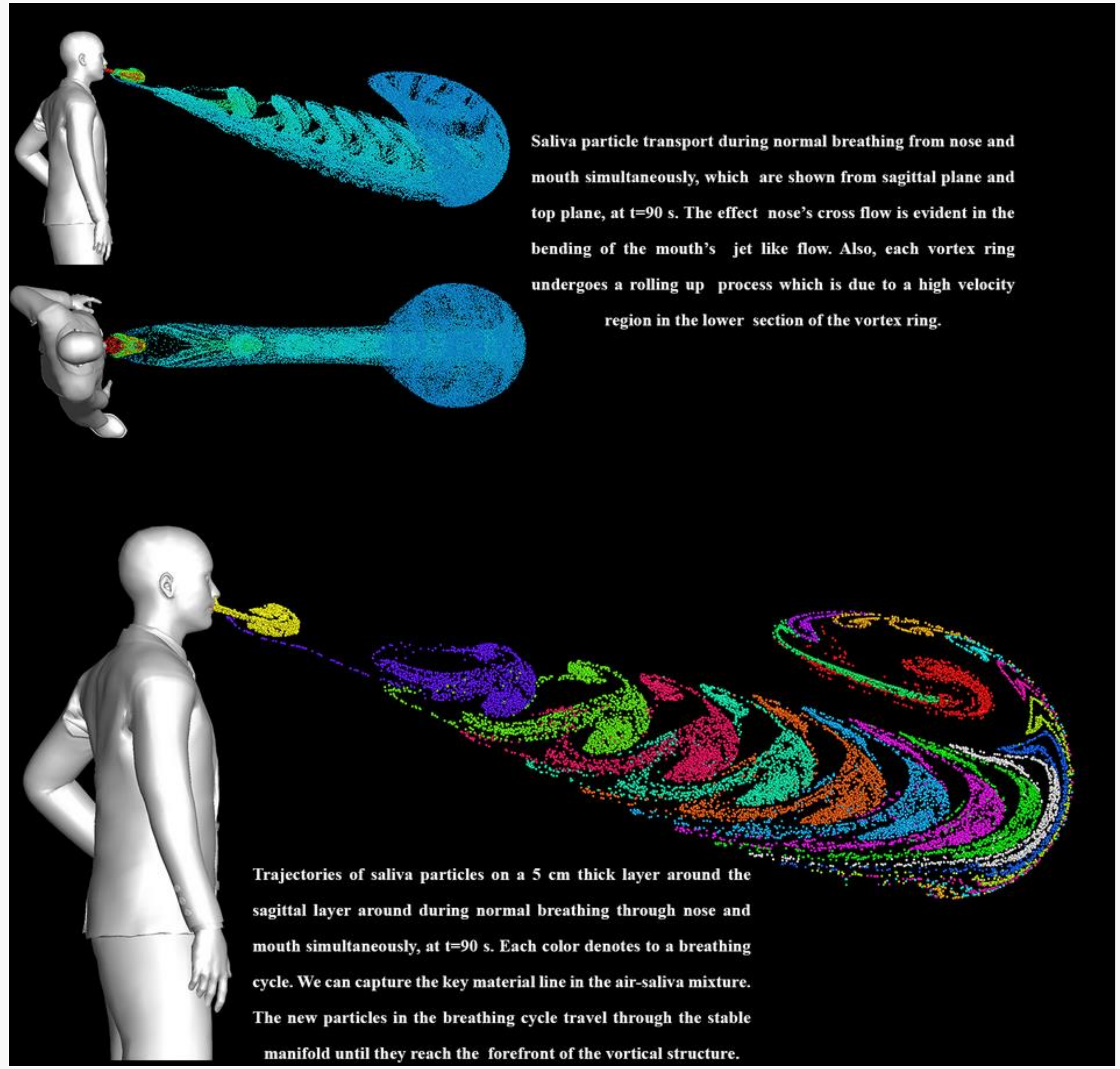
Tornado

Geophysical (atmospheric) fluid dynamics

Fluid dynamics



P0024: Viscous droplet umbrellas
(73th Annual Meeting of the APS Division of Fluid Dynamics 2020)

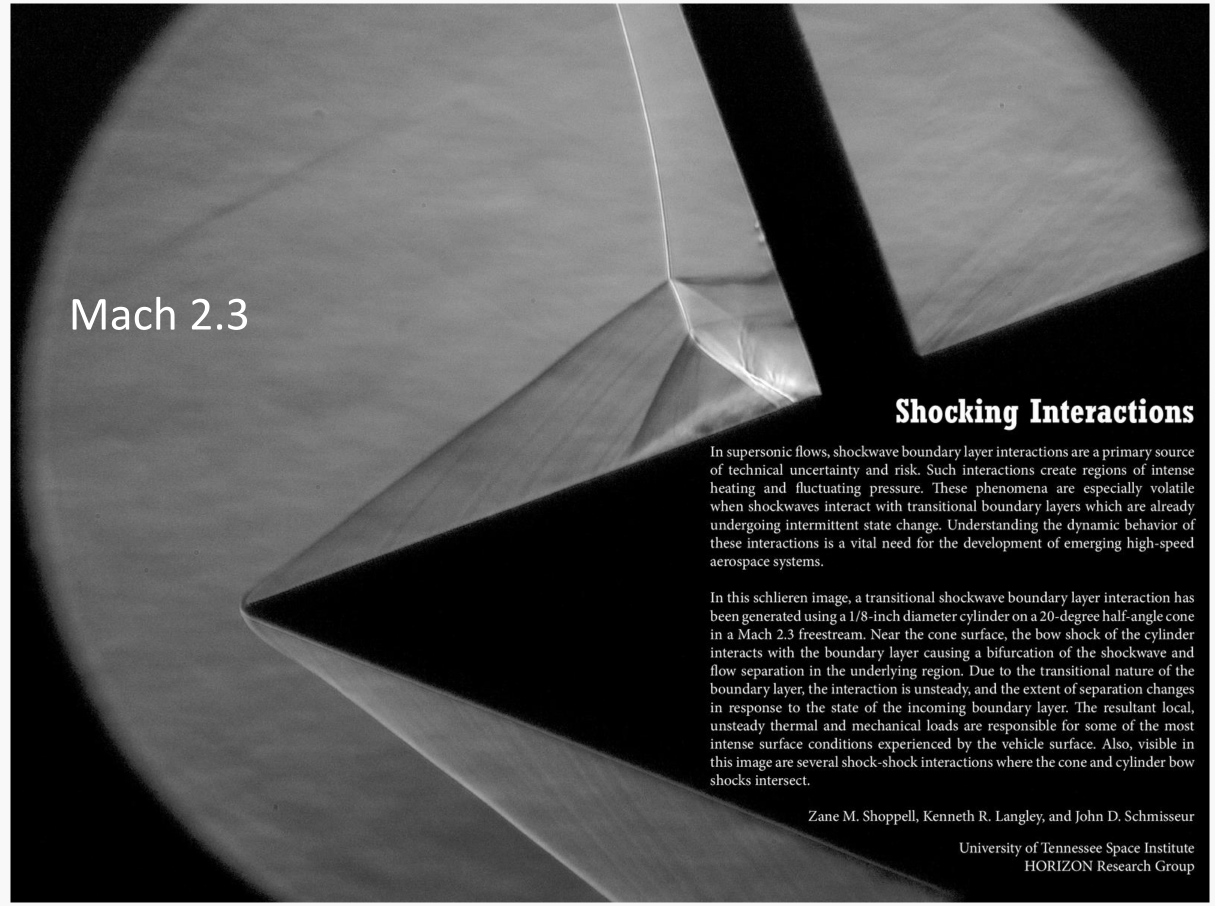


P0012: Saliva particles transport during normal breathing through mouth and nose
(76th Annual Meeting of the APS Division of Fluid Dynamics 2023)

Fluid dynamics

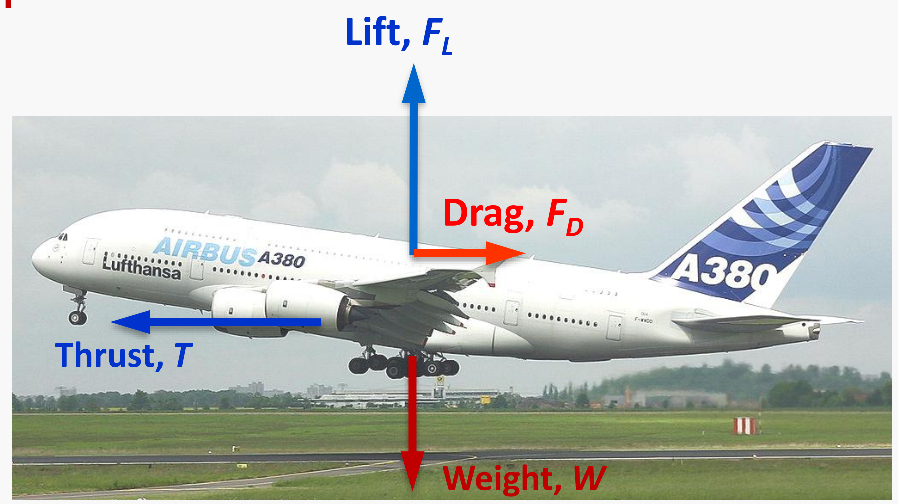
P0015: Numerical Schlieren of the X-59 QueSST
(74th Annual Meeting of the APS Division of Fluid Dynamics 2021)

The X-59 QueSST (Quiet SuperSonic Technology) is a partnership project between NASA and Lockheed Martin with the primary objective of solving one of the most persistent challenges of supersonic flight: the sonic boom.



P0040: Shocking Interactions
(75th Annual Meeting of the APS Division of Fluid Dynamics 2022)

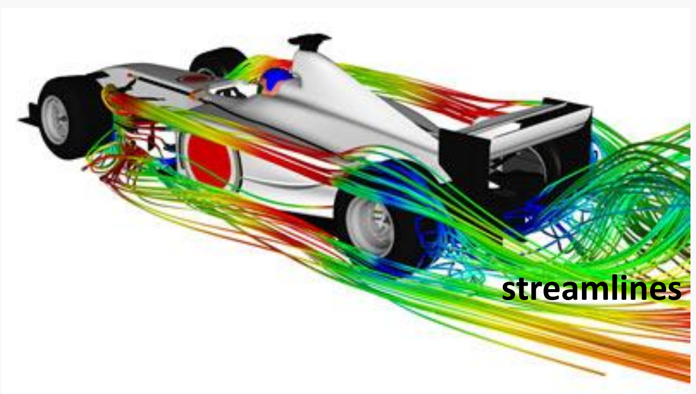
Fluid dynamics



Airplane aerodynamics

F-16 Fighter plane

Rocket launching
(SpaceX Falcon 9)



Racing car aerodynamics

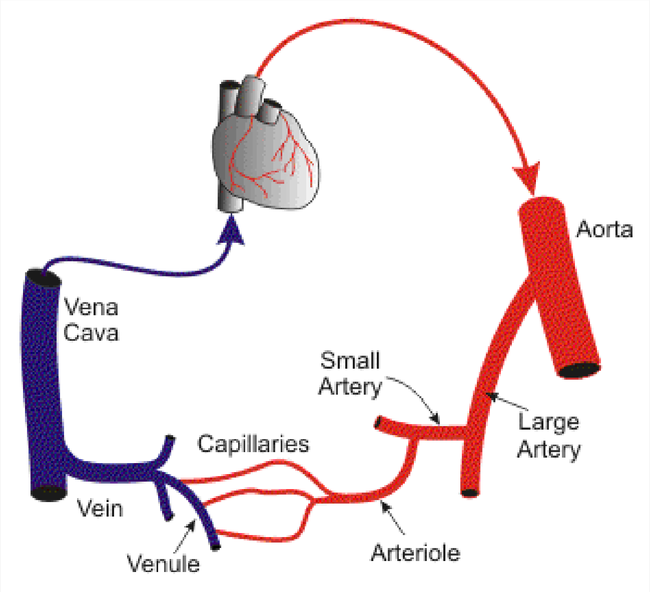
High speed train (320 km/hr)

Offshore wind turbines

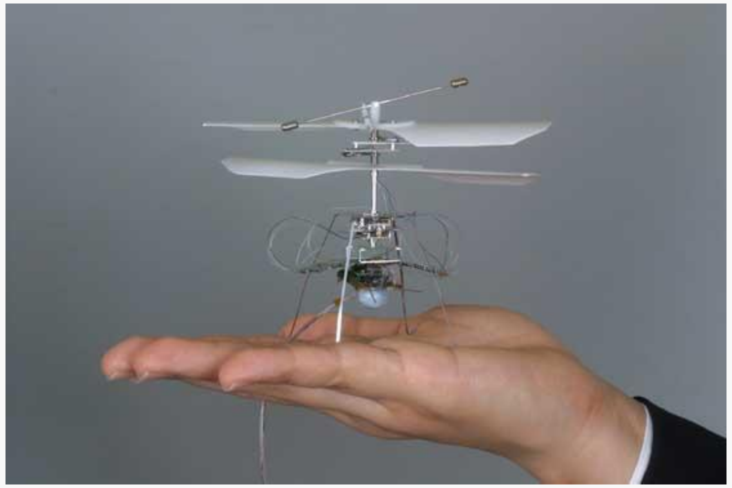
Fluid dynamics

Flying of birds

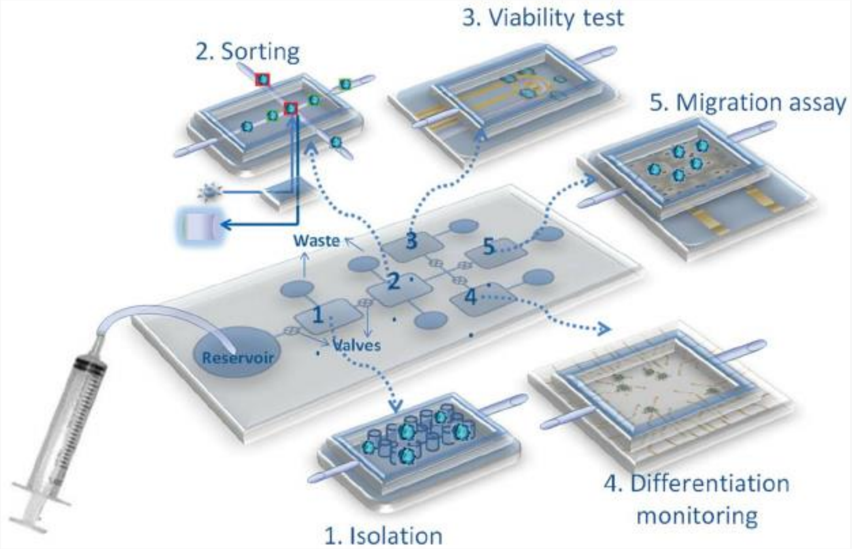
(Biomimetics)



Blood flow through vascular network



Micro Unmanned Air Vehicle (μUAV)



Lab-on-a-chip (LoC) microfluidic device

Fluid Flow at Microscale

At the **microscale**, the interaction between the fluid and solid wall is different than that at the **macroscale**. Fundamental studies have shown that the **continuum hypothesis** may not be valid at microscale and some specific effects may be present that can alter the fluid flow and heat transfer characteristics significantly.

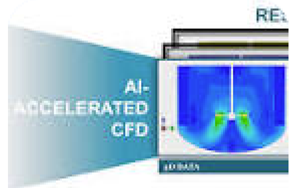
At the **microscale**, **surface area to volume ratio is much larger**, which results in

- increased surface forces, which may produce **large pressure drops**,
- **Increased viscous dissipation** (small length scale, large velocity gradient);
- **decreased inertial forces**, which allows diffusion and conduction processes to become relatively more significant;
- **increased heat transfer**, which may lead to variable fluid properties and
- **thermal creep** (The thermal creep is defined as the macroscopic movement of rarefied gas molecules induced by a temperature gradient from lower to higher temperature zone).

Therefore, these effects need to be considered to predict the fluid flow and heat transfer characteristics.

AI in Fluid dynamics

AI Overview



AI, particularly machine learning, is transforming fluid dynamics by **enhancing computational fluid dynamics (CFD), optimizing flow control, and improving simulation accuracy**. AI techniques are used to accelerate CFD simulations, analyze real-time flow, and even control complex fluid interactions. This integration allows for more efficient design of aerodynamic models, better turbulence modeling, and advancements in fields like weather forecasting and energy systems.

Elaboration:

Accelerating CFD Simulations:

AI, especially machine learning algorithms, can significantly reduce the computational time required for CFD simulations by learning patterns from large datasets and making predictions more efficiently.

Improving Simulation Accuracy:

AI models can be trained on experimental data or more accurate CFD simulations to refine models and improve the prediction of complex fluid flow behaviors.

Optimizing Flow Control:

AI techniques like reinforcement learning can be used to develop and control fluid flow, for example, in boundary layers to reduce drag or improve efficiency.

Real-time Flow Analysis:

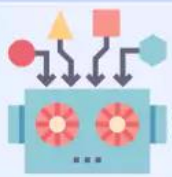
AI models can be deployed in real-time to analyze CFD simulations and provide feedback during testing or actual operation, enabling more dynamic and responsive design optimization.

Applications:

- **Aerodynamics:** AI can be used to predict drag coefficients, optimize airfoil shapes, and improve the performance of aircraft and other vehicles.
- **Turbulence Modeling:** AI can help develop more accurate and efficient turbulence models, which are crucial for simulating complex fluid flows.
- **Weather Forecasting:** AI algorithms can be used to improve the accuracy of weather models and predict weather patterns more reliably.
- **Energy Systems:** AI can optimize the design of wind turbines, hydraulic structures, and other energy systems, leading to increased efficiency.

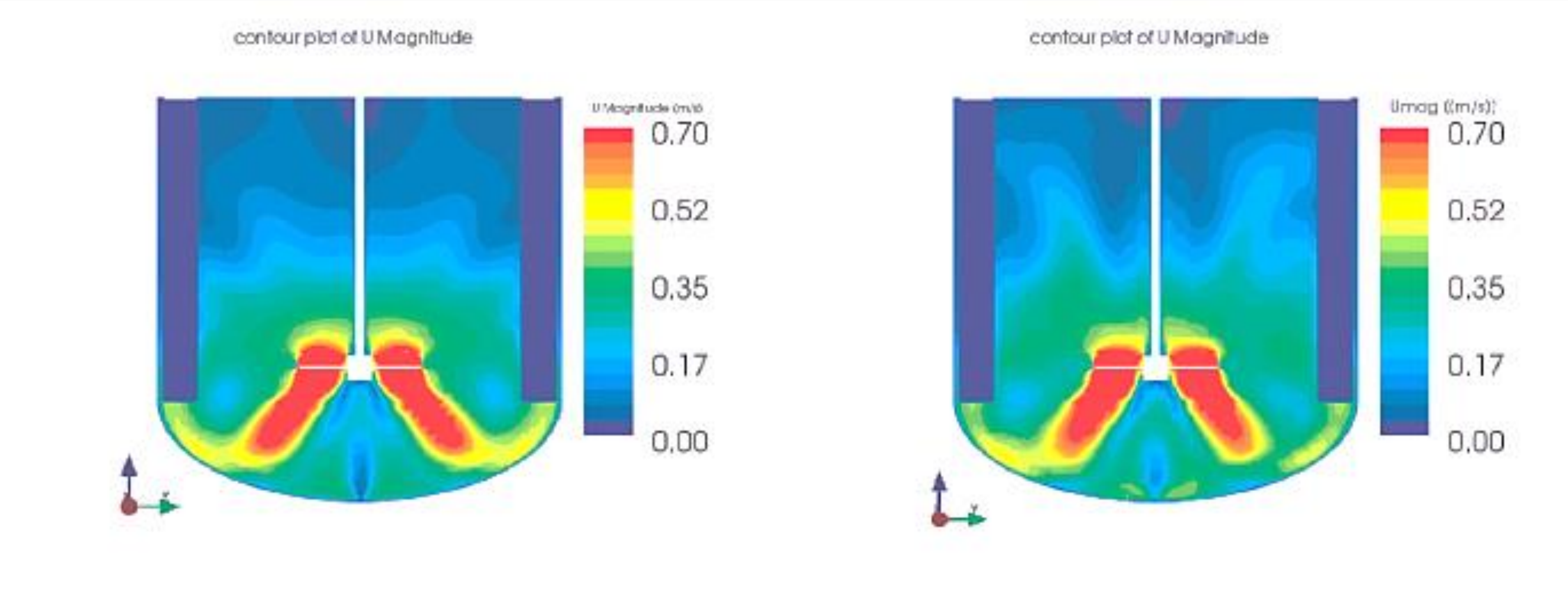
Source: AI overview in Google search

AI in Fluid dynamics

Approach	Accuracy	What is needed?	Gives result...
 **experimental testing**	Very High	Physical prototype Laboratory	in days
 **CFD**	High / Very High	Physical models Skills (experience) HPC or cloud rental	in hours
 **human brain**	Biased	Skills (experience)	in seconds
 **Machine (Deep) Learning**	High / Very High	Data from CFD / experimental testing	in (milli)seconds

A comparison of various engineering prediction methods in terms of accuracy of prediction, needed resources and speed of prediction

https://www.neuralconcept.com/post/applying-machine-learning-in-cfd-to-accelerate-simulation



(a) CFD (b) AI

https://link.springer.com/chapter/10.1007/978-3-030-77964-1_29

Course Contents

- Fundamental concept of fluid as a continuum; Fluid Properties. (MMR)
- Fluid Statics: basic hydrostatic equation, pressure variation in static incompressible and compressible fluids; Manometers; Forces on submerged plane and curved surfaces; Buoyant force; Stability of floating and submerged bodies; Pressure distribution of a fluid in rotating and accelerating systems. (MMR)
- ***Fluid dynamics: Concepts of system and control volume: Continuity, momentum and energy equations and their applications; Introduction to Navier-Stokes equations. (MTH)***
- ***Pressure, Velocity and Flow measurement devices. (MTH)***
- Introduction to inviscid incompressible flow. (*MMR*)

Text books:

- F. M. White, Fluid Mechanics, 7th Edition, 2011, ISBN: 978-007-131121-2.
- M.C. Potter, D.C. Wiggert, Mechanics of Fluids, 3rd Edition, 2010, ISBN: 978-0-495-43857-1.
- Class lectures will be available at **http://toufiquehasan.buet.ac.bd**

Reference books: (for further reading)

i. Munson, Okiishi, Huebsch, Rothmayer, Fundamentals of Fluid Mechanics, 7th Edition, 2013, ISBN: 978-1-118-18676.

ii. Fox and McDonald, Introduction to Fluid Mechanics, 9th Edition, 2015, ISBN: 978-1118912652.

iii. J. F. Douglas, J. M. Gasiorek, J. A. Swaffield, L. B. Jack, Fluid Mechanics, 5th Edition, 2005, ISBN- 978-0-13-129293-2.

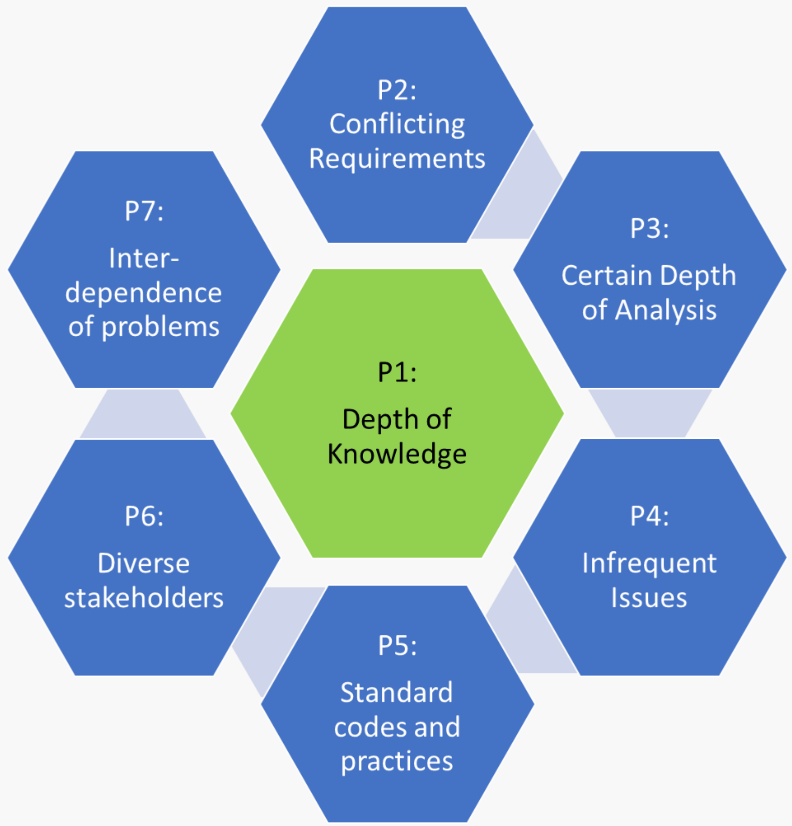
Outcome Based Education (OBE)

- **What is OBE?**
  - a concept/framework for educational programs that focuses on **what the student should be able to do** at the end of a course/program **rather than what he/she is taught**
- **OBE** has been adopted by most well-recognized Accreditation bodies to improve higher educational programs continuously
- **OBE** is being adopted in many of the present day textbooks as well.

Complex Engineering Problems

Engineers	ability to solve Complex engineering problems*
Technologists	ability to solve Broadly defined problems**
Technicians	ability to solve Well-defined problems***

According to *Washington Accord, **Sydney Accord and ***Dublin Accord



Course Outcome (CO) of ME 321

CO No.	CO Statement
CO 1	**Explain** the properties of fluids such as viscosity, vapor pressure, surface tension, and compressibility.
CO 2	**Determine** the pressure in a fluid system using the concept of manometry.
CO 3	**Calculate** the hydrostatic pressure force on a plane and curved submerged surface.
CO 4	**Apply** the continuity, momentum and energy equations to solve fluid dynamic problems.
CO 5	**Analyse** the flow measurement devices.
CO 6	**Apply** the concepts of stream function and velocity potential in simple inviscid incompressible flows.